From
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The Makerspace Workbench

Tools, Technologies, and Techniques for Making

Adam Kemp

DIY/Tools

The Makerspace Workbench

Singe this book! That's right. Author Adam Kemp intends this book to be covered in notes, torn, and slightly charred while sitting beside your next amazing creation. Perfect for any maker, educator, or community, this book shows you how to organize your environment to provide a safe and fun workflow, and demonstrates how you can use that space to educate others.

Don't know what a Makerspace is? This book will tempt your imagination as Kemp clearly details what it means to have a clean, well-lighted work area in which to build, tinker, and dream. That's a Makerspace, and they're popping up everywhere from big cities to small towns to classrooms across the world.

Working from the credo that if you can imagine it, you can make it, *The Makerspace Workbench* outlines the uses and best practice for nearly every tool for people who like to build things, from Scotch tape to a 3D printer, a drill press to a punch, thread cutters to lasers.

From making a lemon-powered battery to constructing a Pythagorean calculator, *The Makerspace Workbench* is your complete guide to finding, establishing, outfitting, and using the tools and technologies that allow anyone to become a Maker with his or her own Makerspace.

Or, as Kemp likes to call it: Paradise.

Filled with practical hands-on advice—like a room grid that allows you to map out your own perfect Makerspace—this book will help you learn how to:

- **Fabricate printed circuit boards**
- **Design for (and use) a laser cutter and 3D printer**
- **Make molds and cast from them**
- **Work with glass**
- **Solder surface mount components**

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by Adam Kemp

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Production Editor: Rachel Steely
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Proofreader: Kiel Van Horn
Indexer: WordCo Indexing Services, Inc.
Cover Designer: Jason Babler
Interior Designers: Monica Kamsvaag and Nellie McKesson
Illustrators: Adam Kemp and Rebecca Demarest
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Making the Space

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In a perfect world, the Makerspace is as common as a coffee shop. You become a member, whether it be paid or free, and when an idea hits you, you know where to go. As you enter the building into a well-lit, clean environment, you see Makers of all ages working tirelessly on their exciting projects. Around the perimeter of the room, you see people on computers with open source CAD software designing circuits and mechanisms, 3D printers extruding parts for more 3D printers, and soldering irons being used to mount components on custom Arduino shields. Near the windows you hear the hum of a squirrel-cage blower removing the smoke from a laser cutter that is meticulously outlining the frame of a quad-rotor helicopter. And in the center of the room, there is a group of students working on their robots for the next FIRST Lego League competition. Paradise.

This dream is quickly becoming reality. Makerspaces of all types are popping up around the world and are opening their doors to the future of Making. For these establishments to become successful at their missions, it is fundamentally important that they start with a good design. This chapter will discuss possible locations for your space, tools for laying it out, and ensuring its occupants have a safe environment to work (Figure 1-1).

Figure 1-1. *My project area.*

Choosing the Location

The first question asked when designing a Makerspace is “Where am I going to put it?” This decision sets the stage for determining the types of equipment, materials, and projects the space can support. It sheds light on just how many people can occupy the space as well as its potential for growth. Choosing the location is mainly dependent on the direction you want the space to go. What kind of projects do you want to support? Are they craft based or do they require sophisticated machinery? This section is designed to assist with this decision and will help develop an understanding of the proposed locale’s benefits and drawbacks. Ultimately, choosing the optimal location ensures that its participants can function safely and effectively while they work.

Understanding the Constraints

Although each location possesses unique design constraints, there are common elements that are universal. In understanding each of these elements and the limitations they expose, you will be better able to choose, design, and ultimately construct your Makerspace. These constraints will also help to determine just what kind of equipment your Makerspace needs. Table 1-1 helps to illustrate different methods and tools required for completing common tasks. It might turn out that your space can get away with simple handheld power tools rather than the larger standing type. Or, that there are different ways for making a hole that doesn't involve a drill.

Table 1-1. Different tools for the same task

Task	Tech Level	Tool
Making a hole in <1/4″ Wood/ Plastic	Low	Mechanical drill or hole punch
	Medium	Hand Drill
	High	Laser Engraver
Making a hole in >1/4″ Wood/ Plastic	Low	Hand drill
	Medium	Drill Press
	High	CNC Router
Making a hole in sheet metal	Low	Sheet Metal Punch
	Medium	Hand drill w/ wood backing block
	High	Pneumatic punch
Making a hole in metal plate	Low	Hand drill w/ hole saw
	Medium	Plasma cutter
	High	CNC Mill
Cutting a profile in wood/ plastic	Low	Hand or coping saw
	Medium	Jig, scroll, or band saw
	High	Laser engraver
Cutting sheet metal	Low	Sheet metal hand shears
	Medium	Floor shear
	High	Pneumatic or electric hand shears
Cutting metal plate	Low	Hack saw
	Medium	Reciprocating saw
	High	Plasma cutter
Constructing a 3D object	Low	Hand model and cast
	Medium	3D Printer
	High	CNC Mill
Soldering a PCB	Low	Unadjustable soldering iron
	Medium	Adjustable soldering iron
	High	Reflow oven
Making circuit boards	Low	Toner transfer and hand etch
	Medium	Photo transfer and hand etch
	High	PCB Mill

Size

The size of your Makerspace is ultimately the biggest constraint. It dictates how many people can safely work at one time, the types and quantity of equipment you can support, and the size of the projects that can be worked on. A good rule of thumb for determining a number of occupants in your Makerspace is to allocate 50 sq. ft. of space per person: that's a roughly 7 ft × 7 ft area. This allotment allows for safe use of floor space, especially as the occupants will be working in a lab environment. You can find more information in the *BOCA National Building Code/1996*, Building Officials & Code Administrators International, Inc., 1996.

Equipment and technology take up space, require power, and often require some amount of ventilation for proper and safe operation. Table 1-2 is a list of common large equipment found in the Makerspace environment and their approximate size and power requirements.

Table 1-2. Common Makerspace equipment

Type	Size (ft)	Power (Watts)
3D Printer	1 × 1	100
Laser Cutter w/ Ventilation	3 × 5	1500
Standing Drill Press	2 × 3	350
Table-Top Drill Press	1 × 2	125
Standing Band Saw	2 × 3	350
Table-Top Band Saw	1 × 2	120
Soldering Iron	1 × 1	75
Heat Gun	1 × 1	1500
Hot Plate	1 × 1	750

Power

At the end of the day, someone has to pay the power bill. This constraint is important to understand as many of the pieces of equipment your Makerspace will use require a lot of power. Tools like heat guns and hot plates as well as equipment like laser cutters and their ventilation systems consume hundreds of watts of energy during use.

There are typically two types of outlets that will be available: NEMA 5-15 and NEMA 5-20 (Figure 1-2). Their design dictates how much energy that electrical branch can supply, specifically 15 amps and 20 amps. If you go over the available current, like you would if you used 4 heat guns on one outlet, you run the risk of tripping a circuit breaker, or in the worst case, starting a fire.

Figure 1-2. *NEMA 5-20 outlets feature a horizontal slot for a 20 amp plug.*

Whether you are creating a public or private Makerspace, it is imperative that you follow your local and state rules and regulations pertaining to fire-code and safety. A good place to locate this information is through the National Fire Protection Association at http://www.nfpa.org and the Occupational Safety & Health Administration at http://www.osha.gov. This book should not serve as the only source of information regarding outfitting and occupying a space, and it is your responsibility and discretion to ensure that your Makerspace follows the rules.

An alternative to calculating power consumption is to use an in-line or inductance type power meter (see Figure 1-3). These devices are designed to measure and display immediate power consumption, power consumption with respect to time, current draw, and voltage. They also have the ability to predict the cost in electricity to operate that piece of equipment, which could prove to be very beneficial for understanding the costs involved in operating your Makerspace.

Power Calculation

With DC circuits, we can simply calculate power using P = IV and, conversely, the current by using I = P/V. This equation holds true for instantaneous power in an AC circuit, yet the average power of an AC circuit is determined based on its power factor. You can calculate your equipment's potential current consumption prior to its use by using the following formula:

$$I = W / (PF \times V)$$

I	Current in amps
W	Power in watts
PF	Power factor
V	Voltage in volts

The *power factor* describes the ratio between the power actually used by the circuit (*real power*) and the power supplied to the circuit (*total power*). This value ranges from 0 to 1 and can be difficult to pin down without a good understanding of the internal circuitry or through physical testing. Typically, resistive loads, like heaters and lamps, receive a 1.0 power factor. Equipment containing motors have a power factor less than 1, requiring more power than would be necessary if the circuit were purely resistive, and directly correlates to the efficiency of the system. For the most part, the equipment that you will be using in your Makerspace will not be drawing a large amount of power. Those that do will typically identify their power requirements either on a sticker or within the documentation.

Figure 1-3. *Digital watt meters can accurately display a piece of equipments' power consumption in real time.*

Ventilation

Nobody wants to work in a stinky room and the fumes emitted by Makerspace technology can quickly become a problem. The necessity for proper ventilation poses a serious design constraint if your Makerspace is going to support equipment that produces fumes. Technology like 3D printers, soldering irons, heat guns and plates, and most especially laser cutters are the primary contributors of potentially harmful fumes. Normal room ventilation systems (Figure 1-4) either recirculate the air after it passes through a series of filters or it is pumped in fresh. As the existing ventilation systems are something that cannot easily be changed, localized vapor removal methods need to be implemented.

Figure 1-4. *The ventilation system directs unwanted fumes outside of the building.*

Noise

The fact of the matter is this: tools make noise. On paper this might not seem like a very big issue, but the quantity of noise a machine generates can and will dramatically affect the layout of a Makerspace. This constraint is especially important to consider when implementing Makerspaces in schools and libraries. Even though these Makerspaces might be located in a room separated from the rest of the building, most commercial structures have drop ceilings and false walls. Sound also has the tendency to travel through duct work and will "broadcast" the Makerspace's activities throughout the rest of the building. Table 1-3 illustrates some of the more common, and noisy, Makerspace equipment and just how much noise you can expect them to produce while in operation.

Table 1-3. Equipment noise comparison

Reference	Tool/Equipment	Noise Level (dB) [a]
Rock band		110
	Hammer	100.4
Lawn mower		100
	Reciprocating saw	95.5
	Band saw	91.3
Blender		90
	Hand Drill	89.9
	Hack saw	89.7
City traffic		85
	Laser engraver w/ exhaust	82.2
Vacuum cleaner		75
	Drill press	72.3
Normal conversation		60

[a] Noise level readings were taken approximately 3 ft from the source using a TENMA 72-860 sound-level meter

If your equipment produces a lot of noise, you'll want to get some ear protection (Figure 1-5).

Figure 1-5. *Ear protection should always be worn when working in a loud environment.*

The Library Makerspace

The public establishment of a Makerspace is a marvelous idea. It acts as a common place for our youth to learn and explore engineering concepts, community members to organize and share designs, and it offers an extension to the classroom environment. Libraries happen to fit this bill perfectly. With their endless source of research materials, Internet access, and public atmosphere, what better place for a Makerspace. Wouldn't it be nice to have your public library support the basics for Making? Why shouldn't it?

Most libraries have allocated space that patrons can reserve for nonprofit events that consist of either an isolated room or a specific section of the library's floor space. Optimally, the library has space allocated for long-term installations. Because every library is different, you should check with your local branch's website for more information. Whereas many Makerspaces rely on equipment that involves substantial setup or is inconvenient to move, having a permanent space is incredibly convenient. If it turns out that the library only reserves its space for short periods of time, the nature and direction of your Makerspace will need to be flexible enough to conform accordingly.

After the space has been selected, it is imperative to inform the library's director about the nature of your Makerspace. This is important to do before you set up because the equipment and practices you intend to employ might conflict with the library's rules and regulations. During this conversation it might be beneficial to emphasize the following benefits a Makerspace can bring to the library and community:

1. It aids to excite young minds about engineering and manufacturing.
2. It can serve as an educational outreach tool for local schools.
3. It will act as an instructional environment for the community.

A public library is the ideal location for a Makerspace, though there are some caveats, the first of which being noise. Anyone who has ever been fortunate enough to bring their child into a library understands the magnitude of this problem. Many a time has the lovely librarians at our local library given my son the death stare for, well, being a child. This noise requirement places a pretty big constraint on the various resources the Makerspace can offer. Tools like drill presses and band saws inherently produce a great deal of noise when operating, whereas devices like the 3D printer and soldering irons do not. If you look at the common Makerspace tools and equipment, you can quickly compile a list that meets the environmental constraints.

> *In addition to the availability of space, each library system is designed to monitor and track its patrons via a unique ID number assigned with the library card. This system could easily be reused by the Makerspace to log user information, record attendance, check-out/in materials and hardware, and so on, making the Makerspace much more consistent and sustainable.*

Another constraint imposed by the library environment is the potential lack of a permanent location. This applies to Makerspaces that operate as a scheduled event that reserves one of the library's common spaces. If this is the case, an effort should be made to propose a more permanent location because it saves time and accommodates long-term projects. In the meantime, let's take a look at how you can design a Makerspace that uses a temporary location.

The last thing you want to do is spend significant time setting up and tearing down your Makerspace. But, even in a nonpermanent location, there are some tricks you can employ that will help expedite this process.

Project Boxes

Project boxes, like the one shown in Figure 1-6, are an effective way of organizing designated project areas and reducing the time required for the setup and teardown of work area equipment. The boxes should be designed to support a specific task and contain all of the equipment and tools required. For example, an Adhesives Project Box would contain a glue gun, glue sticks, epoxy, wood glue, super glue, mixing cups and sticks, and minor surface preparation materials. When the adhesives project is complete, the box can be quickly reassembled and ready to support the next task.

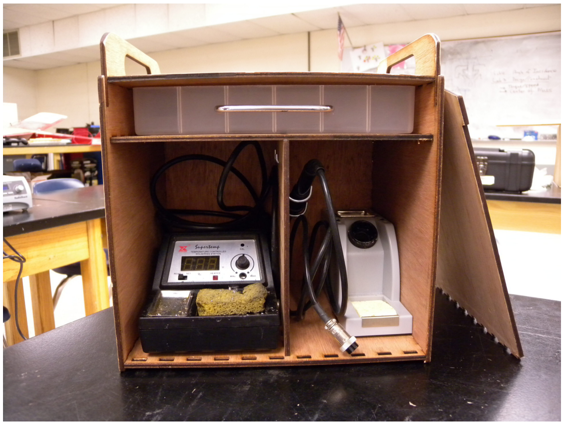


Figure 1-6. *Designated project boxes are a good way to keep work areas clutter free and allow for a quick cleanup.*

Figure 1-7. *Sealable sandwich bags are great for storing loose wires.*

Taming Wires

Even wires that are properly bundled pose a serious organizational problem. A good method for tackling this problem is to keep each, or similar, wires bundled in sealable sandwich bags (see Figure 1-7). This seemingly simple solution is incredibly effective at preventing the "wire monsters" that occur when bundles of cable are shoved into storage. By quickly coiling similar cables and storing them in sealable bags, they are then easily recovered with little mess. It is amazing how much time gets eaten up when trying to untangle a single cable from a nest of its closest friends.

With a little luck and preparation, the limits imposed by the library Makerspace are minor at best. Remember, the goal of your Makerspace should be to provide the most effective work environment possible, and by understanding the limitations beforehand, more time can be spent working on projects.

The School Makerspace

Workshop environments in our schools are disappearing at an alarming rate. In addition, departments like Technology Education are not considered "core" areas, and the idea exists that workshop environments don't develop skills necessary to go to college. As a teacher, I have witnessed firsthand a surge of interest in problem-based curriculum from both our youth and their parents due to its ability to engage students and help them retain the knowledge. This is why the marriage between the classroom and the Makerspace is so potent; it fills the gap between classroom theory and the physical world.

Historically, sparse classroom budgets have been the root cause for a lack of modern equipment in the classroom. This fact has remained true for years when you consider an entry level 3D printer could cost more than $20,000! Now, a derivative of the technology can be purchased with the proceeds of a single bake sale, or even through parent donations. The beauty of the Makerspace is its ability to not only inspire students but accelerate their knowledge intake through exciting and imaginative curricular application. To facilitate this, schools need to consider the design constraints imposed by Makerspace equipment and how it might affect classroom layout.

There are two ways that a Makerspace can be integrated into your school; either as part of the existing classroom environment or as an entity unto itself. Although each present different challenges, they can be profoundly effective in assisting and inspiring students.

The Makerspace Classroom

As part of the classroom environment, the Makerspace mentality and equipment can be instrumental to the success of the curriculum and engagement of the students. Students embrace the responsibility of using technical equipment, and when they see the potential this equipment provides, their excitement will help motivate their peers.

The decision to merge Makerspace and classroom should extend department wide because it helps to improve knowledge retention among students. This idea of *vertical articulation* applies typically to curriculum yet is just as effective when working with equipment. For example, students are educated and conditioned to use calculators in their math classes. When they leave class and go to a science course that needs to solve an equation, chances are they are going to reach for that calculator. If every classroom had a 3D printer, they would reach for that, too.

The benefits Makerspace technology can afford the classroom environment is astounding. One of the largest hiccups that has prevented innovative exploration in the classroom is the presence of standardized curriculum. With the help of Makerspace technology, innovation and imagination can now supplement and support the standardized curriculum, making the classroom more exciting and engaging for student and teacher alike.

Most classrooms integrate the idea of a "lab" or "activity" that takes the students away from the books and requires them to apply the concept in a physical manner. This allocated time is optimal for the education and integration of Makerspace technology. The following are potential content areas in which Makerspace equipment could benefit the classroom environment:

Science

Makerspace technology can be used to assist in the physical modeling and assembly of chemical compounds, cell and bone structures, and in developing an understanding of how data is acquired and analyzed.

Technology and Engineering

Makerspace technology can supplement a wide array of projects that would normally require multithousand-dollar machines. It directly ties in to courses that focus on architecture, design and manufacturing, robotics, industrial and mechanical engineering, electronics, and virtually all other technology education and engineering curricula.

Art

Makerspace technology can provide a medium for a large number of artistic projects. This can include modeling, photography, computer-controlled art, light and sound, and the list goes on.

Mathematics

Makerspace technology can help illustrate many mathematical concepts through the production of physical objects. Equations and their relationships can be physically constructed, altered, and computed all within the classroom.

The Standalone School Makerspace

In the event that the Makerspace cannot coexist with the classroom environment, it might function better as an entity unto itself. This standalone Makerspace can serve as a "go-to" resource for individual classrooms and student projects alike. Because Makerspace equipment can be implemented into areas with relatively large space constraints, the repurposing of a small classroom or teacher workroom can make the decision a breeze.

With any workshop environment, it is important to clearly define the person in charge of the materials and equipment as well as the space's limitations. This supervisor, whether it be teacher or otherwise, is solely responsible for the space's maintenance and upkeep, because classrooms depend on the resources. As you can see, a situation where multiple classrooms are dependent on a single Makerspace ends up in a scheduling and resource nightmare. Compounded with the need for students to be directly involved with using the equipment, it is important to ensure that this space can in fact support the classrooms that depend on it. It isn't fair to bring 35 students into a small Makerspace and expect them to all get a chance to use the equipment. This is why it is so important to understand the Makerspace's limitations in order for it to succeed.

Aside from operating as a classroom resource, the Makerspace can serve as a resource for individual student projects and initiatives. Depending on your school's schedule, there is often time when students are not required to be in class; for example, during lunch, before or after school, or during designated club/activity time. It can also provide a manufacturing resource for student organizations like TSA, FIRST Lego, FIRST Robotics, and Odyssey of the Mind.

The Garage Makerspace

Garages are not just for parking cars. They can contain the world's most elaborate and ingenious creations and if you happen to be one of those fortunate enough to have a garage, we are about to unlock its potential. With today's wealth of open source technology and the "share and share alike" mentality, setting up an in-home Makerspace is easier than ever. The underlying goal of any Makerspace should be to provide an environment that supports and inspires its members to create with tools that were once not possible. The fact that we have tools like open source 3D printers, laser cutters, electronics, and other resources is the result of the overwhelming generosity of the Maker community. This mantra should be reflected in your Makerspace and afforded to willing members of the community.

The garage Makerspace has incredible potential to support local organizations like the Girl Scouts, Boy Scouts, FIRST Lego and FIRST Robotics clubs. By providing a safe and effective work environment for these youth to operate, you are not only doing the community a great service, but are providing them lifelong lessons. This in-home Makerspace has many benefits over the previous two, the primary of which being that you are the boss. The long list of bureaucratic hoops you need to jump through to establish your space disintegrate when you happen to own it. Your only restrictions are the legality and safety of the space itself.

Make sure you understand the legal implications of having individuals outside of your family work your Makerspace, regardless of where it is located. Review your local and state laws regarding your liability with respect to those working in your Makerspace so that everyone is covered in the event of an accident.

The idea of outfitting a garage to function as a Makerspace can get a bit tricky. We are often faced with poor insulation and unfinished walls, missing HVAC vents, sparse electrical connections and last but not least, cars. Yet, with all of the potential drawbacks, the idea of converting a garage into a space for creation and making it available to the desired community is extraordinary.

Project: Equipment Donations and Discounts

If your Makerspace is to function as a nonprofit organization, there is a good likelihood that you can solicit equipment donations or a discount to the listed price from outside organizations. Donations can also qualify as tax-exempt if your Makerspace qualifies under section 501(c)(3) of the United States Internal Revenue Code or the donation is made to the qualifying library or school in which you are established. This project is designed to assist you in determining what equipment, materials, and so on you think could be donated as well as provides a strategy for contacting the potential donor.

You can find out more about how your Makerspace might qualify as tax-exempt by visiting the IRS's website at www.irs.gov.

Regardless of your tax-exempt status, the nature of the Makerspace is attractive to outside organizations because it serves as a hub for inspiring future engineers. Many organizations would love to either sponsor or donate items to your Makerspace if they see that their resources will be used for the betterment of the community. This project is designed to walk you through the preliminary steps for soliciting a donation or discount to items for your Makerspace and helping to alleviate potential financial burden.

Materials

Provided in the following sidebar is an "Industry Contact Form" that walks you through all the steps necessary to research a specific needed component, contact a potential supplier, and present your project in a way that illustrates to the organization the benefits of the donation or discount. Good luck!

Procedure

Step 1

Start by researching the item that you believe could be obtained through donation. The objective is to conceptualize equipment or materials whose donation would ultimately benefit the company. The potential donor might have overstock inventory, damaged goods, or a stockpile of materials headed to the dump, all of which are gold for a Makerspace. These items end up consuming space and therefore resources, making them prime for donation. Be sure to record the company name and contact information on the Contact Form during your research.

Step 2

After you have determined your item, its important to record specifications that can help the potential donor understand what you are requesting. Make sure you focus on specifications like model, part number, dimensions, quantities, color, and any other specification that you require. This helps the company spend less time trying to understand your request and will aid them in directing you to the individual who can better assist you. If you do your homework, the results will be evident.

Step 3

Time to make the call. Making a phone call rather than sending an email is not only more professional, but shows that you are taking the time to make the request in person. It is a lot harder to ignore a phone call than it is to delete an email. The Contact Form contains example dialogue that will assist you in your request. Good luck with you phone call and your potential donation/discount!

Designing the Space

Whether its nestled in a home basement or spread across a warehouse, the design and layout of your Makerspace is the most important initial decision you can make. It will ultimately dictate the ability of its Makers to work efficiently and safely as well as shedding light on the types of equipment it can sustain. The types of work surfaces, shelving, computer desks, and seating all play a part in the flow of your space and are elements that can be visualized prior to actually being installed. All three locations previously discussed have predetermined layouts with little room for modification. Unless you have the authority to put a new window in the side of a library or a classroom, or building permits to poke a hole in the side of your house, we end up working with what we have. It is now up to your own ingenuity to shape and mold your future Makerspace into a form that not only supports your equipment, but provides an effective work environment for its occupants.

Check with your local government authorities to verify the need for building permits when modifying your existing structure. Tasks as small as moving an outlet can require a permit.

Makerspace Industry Contact Form

Illustrating the mission of your Makerspace to the layman is no easy task, especially if they are unfamiliar with the Maker movement and its associated technologies. If your Makerspace requires new equipment or materials, you might be able to solicit a donation or discount by directly contacting industry representatives. Sources of assistance can range from local businesses to online distributors; the possibilities are truly endless. By making a phone call in lieu of writing an email, you are establishing a more personal relationship that is harder to disregard, and who knows, you might end up with a continuing sponsor. During this conversation, you will be briefly describing your project and the component you require in a manner that is professional and reflects the legitimacy of your project.

Research the Donation

Prior to making your phone call, it is important to know the exact specifications of the equipment or materials you are requesting (Table 1-4). This helps to limit the amount of explanation required when making your contact. The rule of thumb to follow is: time is money. If you lack confidence with your request and ramble or are unclear, the chances your request is successful dramatically decrease.

Table 1-4. Company and equipment description

Company Name	**Phone Number**	**Website**	**Component Description**
Part Name	**Part Number**	**Size/Qty**	

Make the call

Introduce yourself professionally; for example, "Hello, my name is ______________ , and I am establishing a Makerspace workshop for my local community. This workshop is designed to educate today's youth through the use of open source software and technology."

Briefly describe your intentions; for example, "For our Makerspace to succeed and provide the most effective environment for our patrons, we need a ______________. Would your company be willing to sponsor us by donating or offering a discounted price to this equipment/material?"

They will either say "No," and you say "Thank you for your time," and you should try another company.

Or, they say something along the lines of, "Yes, let me transfer you to the ___________ dept." and you start the process again.

Make sure you use *Please, thank you, yes Ma'am/Sir*. You might think this is not necessary, but you would be surprised at how much being polite can help.

Complete the following during your phone call (Table 1-5):

Table 1-5. Conversation log

Contact Name	**Extension**	**Successful Donation Y/N**
Details		

Remember, if you receive a donation or discount, make sure you provide a written "thank you" letter to the donor. This not only maintains good rapport with your potential vendors, but aids in establishing a continuing relationship.

This chapter discusses a variety of design considerations and rules that can be followed to ensure the success of your new Makerspace. Although there are a number of ways to begin designing your space, the objective is always the same: pPlan first, and then act.

Nobody likes to "rub elbows" while they are working on their project. It is especially important when working with machines or potentially dangerous tools that enough free space is available at all times. This safety zone ensures that multiple people can be working in the same general area while maintaining a safe operating distance. A good rule of thumb for establishing safety zones is to give 3 sq ft of space around anyone using a hand tool, tabletop drill press, or soldering iron, and 3 ft radius around any standing piece of equipment (for example, a band saw, standing drill press, or lathe). Tools like a horizontal band saw or table saw will require more space to accommodate for the use of large materials.

Work Areas

You can never have enough space, especially when it comes to work areas. These spaces should cater to both the project and the personality type of the Maker. Some people like to think aloud and spread their projects to the limits of the work area, whereas others tend to work with more methodology and organization.

Connect power tools and equipment to outlet timers. This helps eliminate problems related to equipment being left on after use. Just make sure they are rated at a high enough power level.

One method for catering to these differing work methods is to designate quiet and loud work areas. The quiet work area should facilitate project types that don't involve a great deal of mess or noise. This type of work area is actually better at accommodating more people than the loud area because the environment is less physically hazardous. The loud work area should be able to handle larger, more intensive project types. These could require power tools and pneumatics, thus requiring less people per square foot so as to reduce the potential for injury.

Each work area should facilitate a specific type of project and should contain all of the resources necessary to operate in that area. Makerspaces commonly have the areas listed in Table 1-6, and vary depending on the direction of the Makerspace.

Protect your work surfaces (see Figure 1-8). Regardless of your Makerspace's location, it is important to keep your surfaces clean. An easy way to accomplish this is by covering the surfaces with Masonite. This material, which is what clipboards are typically made of, provides a smooth and resilient surface that is relatively heat and moisture resistant, not to mention inexpensive.

Figure 1-8. *Covering work surfaces with inexpensive and durable materials helps to prolong the life and quality of the work surface.*

Table 1-6. Makerspace work areas

Work Area	Space Requirement	Power Requirement	Primary Function
Computer Station	Small	Large	Supports computers, printers, and common software

Work Area	Space Requirement	Power Requirement	Primary Function
Soldering Station	Small	Small	Contains necessary soldering equipment, ESD protection, and support electronics
Electronics Workbench	Medium	Small	Houses electronics components and test equipment
Project Area	Large	Large	Open floor and project work surfaces
3D Printing Station	Small	Small	Supports 3D printer, computer, and filament
Laser Engraving Station	Medium	Medium	Supports laser engraver, ventilation and laser-able materials
Power Tool Area	Large	Large	Supports standing and portable power tools, open floor, and work surfaces

Devices like electrical ceiling drops (mainly for the garage and school Makerspace) and extension cord covers should be used in lieu of exposed cords as they greatly improve work flow and personal safety.

Every Makerspace needs computers. They act as the gateway for project research, design, and control as well as provide support for many pieces of equipment. The main decision behind establishing designated computer stations (Figure 1-9) is whether you will be providing desktop or portable computers. Each has their advantages yet require different infrastructure to support.

Figure 1-9. *The computer station not only contains a computer, but has a small amount of open work space for writing and working on projects.*

If you choose to use desktop computers, which are often available in a library or school environment, it is necessary to allocate enough surface area to support the computer and its peripherals. Depending on the size of the computer systems, a 6 ft × 2 ft table is capable of supporting two computer stations comfortably. The benefit of having dedicated computer stations is a more consistent work environment. You know where your computers are at all times, and can easily account for the necessary space required for their use.

Following the portable route, you will need to take into account the need for charging the systems or provide ample access to electrical outlets at the different workstations. The advantage of using portable computers in this environment is the lack of need for dedicated computer work surfaces. This area can now be repurposed to support more equipment, soldering stations, and so on. However, there is a pretty big drawback with having a large quantity of power cables traveling around the space, which could result in a tripping hazard.

Project: Makerspace Layout Tool

The initial inclination when designing a space is to sit behind a computer and lay it out by using AutoCAD. Although this is an effective means for designing a space, physically laying it out by hand can yield better results (see Figure 1-10). There is something to be said about physically connecting with your design and the flexibility of using nonvirtual materials to visualize the environment. This project is designed to help you begin the layout process by analyzing your available space, tools, and materials in a way that produces an effective design for your Makerspace.

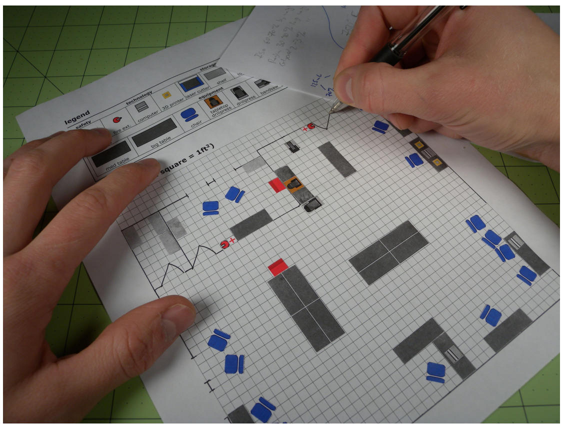


Figure 1-10. *Print out the layout tool and cut out the examples to begin designing your space.*

Materials

You can find the files for this project on Thingiverse.com.

Equipment Checklist		
Type	**Size (ft)**	**Power (Watts)**

Procedure

Step 1

To begin, you need to determine how much space you actually have available. Starting at one corner of the room, begin to measure the wall length and illustrate the wall on the Layout Paper. Remember, each cell represents a 1 ft × 1 ft area. Indicate the location and width of any doors, windows, or other obstruction that influence the spaces design and work-surface placement. Continue this process until the perimeter has been fully outlined.

Step 2

Reference two common walls and use your tape measure to determine an approximate X/Y coordinate for any feature located internal to your space and illustrate them on the Layout Paper. Be sure to include electrical outlets, support features (load-bearing poles, interior walls), floor drainage, and lighting. These features are important to note because they will set the constraints for equipment placement.

Step 3

Record the tools, materials, and workspaces you currently have or would like to have in your Makerspace. Using your tape measure, record the footprint dimensions of your current equipment and illustrate them on the supplied Available Equipment Checklist. It is also a good idea to consider growth and research the dimensions of equipment you would like to acquire at a future date. This will help you better organize the initial layout of your space (Figure 1-12) and will make future expansion easier.

Step 4

You should now have an accurate representation of your space's structural components and available utilities and can begin to determine how your equipment, materials, workspaces, and storage might be organized. Using the Available Equipment Checklist and Sample Equipment Sheet, cut out

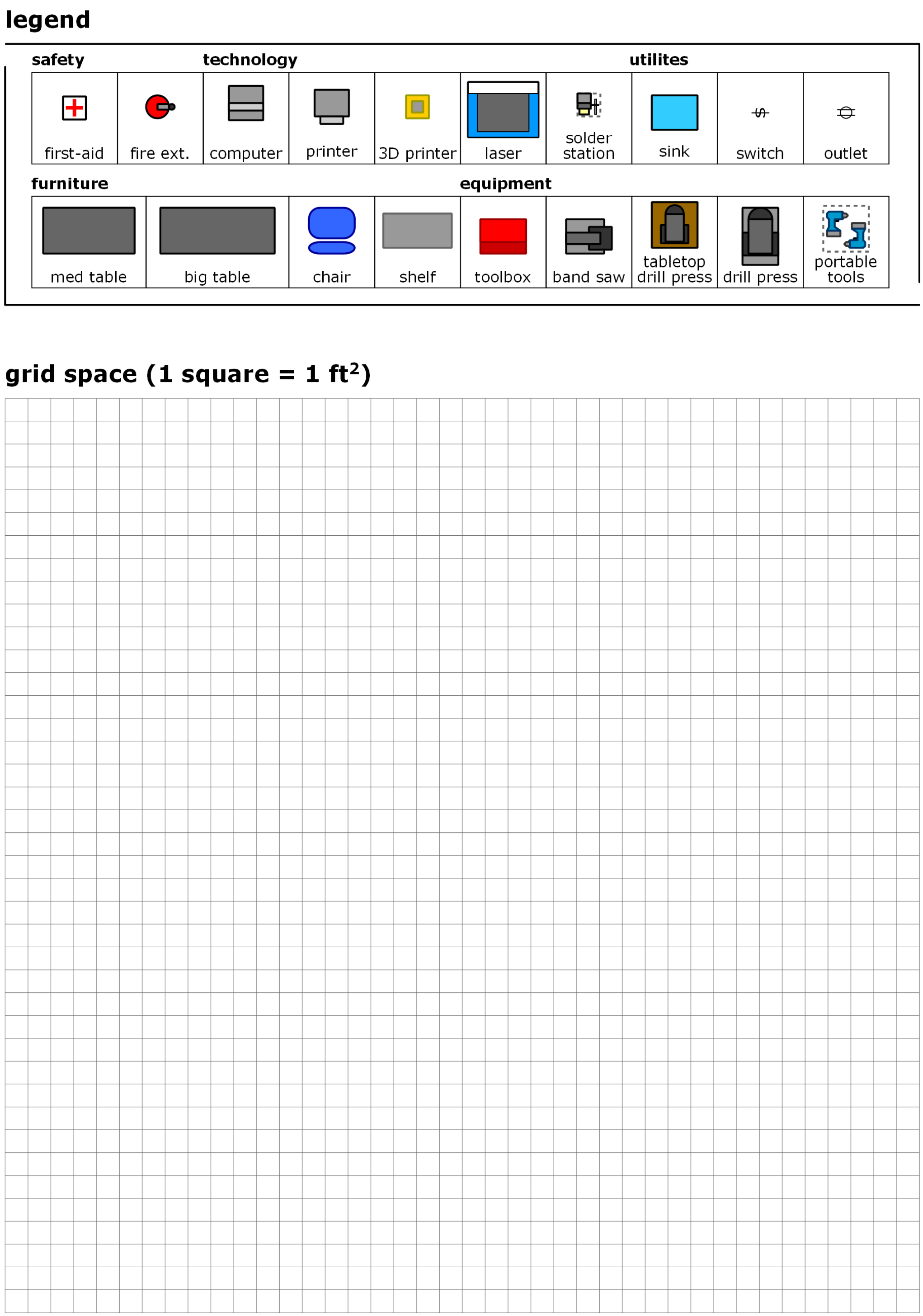


Figure 1-11. *Makerspace Layout Tool.*

and begin to position them in your space. Make sure you account for work-zone safety rules, position equipment near their required utilities, and envision how the members might utilize the space.

Safety

Not only should safety be the main concern when designing and laying out your Makerspace, but it should be a topic that is often addressed during its operation. Whenever students enter into a laboratory environment and are expected to use equipment, they are required to pass a series of Safety Tests that are designed to verify competency in the safe operating procedures of both the space and its equipment. With respect to the more public environment of the library and garage Makerspace, it is imperative that an understanding of the safety rules and regulations your Makerspace follows are clearly understood.

The more you encourage safe practices, the less likely you will have to deal with damaged equipment and tools, poor work conditions, and, in the worst case scenario, injury. So, take the time to illustrate how you want your Makerspace to operate and ensure that everyone conforms to your rules.

Safety Tests

A great way to welcome new Makers into your Makerspace is with a Safety Test! Many of us cringe at the sight of written assessment, but rest assured, these tests are a little different. It is often difficult to assess skill sets, especially when it comes to the safe use of equipment. Regardless of what someone says about their previous exposure and use of any of your Makerspace's equipment, it is mandatory that you administer some form of safety assessment and the test taker receive a score of 100 percent. These safety tests are used to both evaluate the member's written knowledge regarding the proper use of equipment as well as her ability to physically demonstrate her skill. The goal of these tests are not to prohibit the equipment's use; rather, they are to shed light on who needs guidance until they reach a skill level at which they can operate autonomously. The following safety tests can be used to help maintain a safe working environment for you and your space's members.

General Makerspace Safety Test

The following test is designed to assess your comprehension of the safe operating practices required by our Makerspace. Answer the questions to the best of your ability.

True/False and Explain

1. T/F: Safety glasses and safety goggles offer the same type of protection.
    a. Answer:
    b. Explain:
2. T/F: Protective eye covering should only be worn when working with tools that are potentially dangerous.
    a. Answer:
    b. Explain:
3. T/F: Small cuts and scrapes do not require the attention of the instructor/supervisor.

a. Answer:

b. Explain:

4. T/F: It is acceptable to leave a work surface cluttered while not in use.
   a. Answer:
   b. Explain:
5. T/F: Personal items such as book bags can be left on the floor while you work.
   a. Answer:
   b. Explain:
6. T/F: Tools should only be used for their intended purpose.
   a. Answer:
   b. Explain:
7. T/F: Electronic devices such as soldering irons should be left plugged in if someone else is waiting to use it.
   a. Answer:
   b. Explain:
8. T/F: Tools should be kept in an organized location.
   a. Answer:
   b. Explain:
9. T/F: Help should be requested whenever large materials, equipment, or work surfaces need to be moved.
   a. Answer:
   b. Explain:
10. T/F: When stocking a shelf, the heaviest items should be placed on the bottom.
    a. Answer:
    b. Explain:

Completed by:

Date:

Checked by:

Date:

General Makerspace Safety Test Answer Key

1. Safety glasses and safety goggles offer the same type of protection.
   a. **Answer**: True
   b. **Explanation**: Both are designed to protect your eyes from foreign objects.

Glasses tend to work better for individuals who do not currently wear glasses, wheras goggles tend to be more comfortable. The important feature to note is the glasses impact rating. Look for a "+" mark on the lens, which indicates the glasses conform to high-velocity standards.

2. Protective eye covering should only be worn when working with tools that are potentially dangerous.
   a. **Answer**: False
   b. **Explanation**: Just because you are not working with a potentially dangerous tool, doesn't mean that you cannot be injured. If anyone in the room is working with a tool that could potentially be dangerous, everyone must wear eye protection.
3. Small cuts and scrapes do not require the attention of the instructor/supervisor.
   a. **Answer**: False
   b. **Explanation**: Regardless of the severity of the injury, the instructor/supervisor must be notified. This is important because it helps to maintain a clean and controlled work environment.
4. It is acceptable to leave a work surface cluttered while not in use.
   a. **Answer**: False
   b. **Explanation**: Work surfaces should be kept as clean as possible so as to avoid potential injury.
5. Personal items such as book bags can be left on the floor while you work.
   a. **Answer**: False
   b. **Explanation**: Personal items, especially those with straps, pose a serious tripping hazard.
6. Tools should only be used for their intended purpose.
   a. **Answer**: True
   b. **Explanation**: By using a tool as it was intended, the lifespan of the tool is dramatically increased. Common mistakes include using screwdrivers as pry-bars, wrenches as hammers, and hex keys on Torx bolts.
7. Electronic devices such as soldering irons should be left plugged in if someone else is waiting to use it.
   a. **Answer**: False
   b. **Explanation**: Safety should never be sacrificed in an effort to save time.
8. Tools should be kept in an organized location.
   a. **Answer**: True
   b. **Explanation**: This helps to maintain an orderly work environment.
9. Help should be requested whenever large materials, equipment, or work surfaces need to be moved.
   a. **Answer**: True
   b. **Explanation**: Following this practice ensures the safe relocation of said objects. Trying to move them by yourself could result in the unintentional injury to yourself or those around you.
10. When stocking a shelf, the heaviest items should be placed on the bottom.
   a. **Answer**: True
   b. **Explanation**: Following this rule helps to prevent unintended injury due to items falling from an elevated surface.

Hazardous Materials

Virtually every material and compound has been analyzed and a material safety data sheet (MSDS) has been generated by its manufacturer to ensure safe handling. Even water has an MSDS! Each sheet illustrates the material's chemical identification, hazard identification, composition, emergency and first aid measures, fire-fighting measure, accidental release measure, precautions for safe handling and storage, exposure control measures, physical and chemical properties, stability and reactivity data, and the list goes on. So how can we use an MSDS to better understand how to ventilate the Makerspace? Well, it's quite easy.

ABS, the common feedstock for 3D printing, has an MSDS that reports all of the potential hazards encountered when handling the material. During printing the feedstock is melted and in turn releases volatile organic compounds (VOCs) into the air, which need to be contained in order to provide a safe and healthy work environment. The sheet for ABS states the following:

Hazards Identification
: Vapors and fumes from heat processing may cause irritation of the nose and throat, and in cases of overexposure can cause headaches and nausea. If affected, remove to fresh air and refer to a physician for treatment.

Exposure Controls/Personal Protection
: Local exhaust at processing equipment to assure that particulate levels are kept at recommended levels.

So you see from the MSDS for ABS that it is necessary to appropriately ventilate the exhaust fumes from your 3D printer (as shown in Figure 1-12) in order to maintain a healthy and safe environment. Nobody wants to barf on their printer, right?

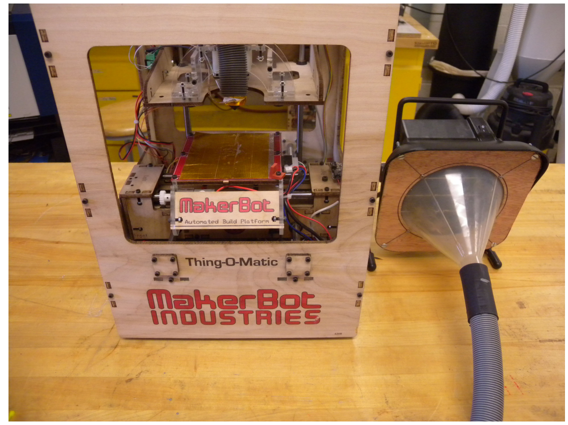


Figure 1-12. *Soldering fume extractors can be used for ventilating the 3D printer when printing materials like ABS.*

Some of the materials you might encounter in your Makerspace, primarily solder paste, require refrigeration. This can pose a huge health risk if these materials are stored in the same refrigerator where food is kept. It is *highly* advised that you acquire a separate refrigerator and clearly label it as "NOT FOR FOOD ITEMS!" and add a Mr. Yuck poison control sticker.

Other materials might need to be stored in an appropriate flame-resistant cabinet (Figure 1-13). This cabinet is designed to isolate both the inside of the cabinet from a fire in the room, should one occur, and the outside of the room if something inside the cabinet were to ignite.

Figure 1-13. *Flammables should be stored in an appropriate cabinet to help prevent unintended fire.*

The general rule when working with potential hazardous materials is to fully understand the extent of the hazard before handling. Every Makerspace should have a hardcopy set of MSDS sheets for every hazardous material present in the space and the phone number for Poison Control readily available. When it comes to safety, you can never go too far. The integrity of your space and the well being of its members is crucial to its success.

Ventilating Your Equipment

Many of the tools found in a Makerspace produce potentially harmful fumes while in operation. Soldering, 3D printing, and laser cutting are the main sources for unwanted fumes, and it is important to employ a proper method for ventilating the area. Generally, it is necessary to have at least one source of fresh air for your Makerspace, whether it is a window, roof access, or pre-existing ventilation system. Always refer to your state and local building codes when choosing and installing any ventilation system.

Ventilating Your Soldering Station

When you begin to solder, you will notice a fair amount of white smoke rising from your project. *Don't worry!* This is normal and doesn't mean that you have released the dreaded "white magic smoke" that occurs when a component is overpowered or short-circuited. The smoke that you see is released from the flux that is present in the solder (this is discussed in detail in Chapter 2.

> *Each manufacturer uses a different flux formulation for their solder. It is important to acquire the appropriate MSDS sheet and be aware of the risks involved with handling and exposure to the flux vapors.*

Even though the short-term exposure to solder fumes is not usually an issue, it is better to be safe than sorry. This is especially important if the Makerspace is in a room without proper ventilation or if there is a concern for anyone with a respiratory problem. One of the easiest ways to tackle flux fumes is to use a localized fume extractor like the Weller WSA350. They are portable, relatively inexpensive, and are great at tackling fumes. An extractor such as this relies on an activated carbon filter and a high-powered fan to extract noxious components from the air.

Ventilating Your 3D Printer

3D printers can produce fumes that cause headaches and nausea if overexposed and thus require fume extraction so as to provide a safe working environment. This is not necessary for most high-end printers such as those from Stratasys because they handle fume extraction internally. Yet for the vast amount of low-cost 3D printer designs and sizes, it is necessary to install a system with some degree of flexibility.

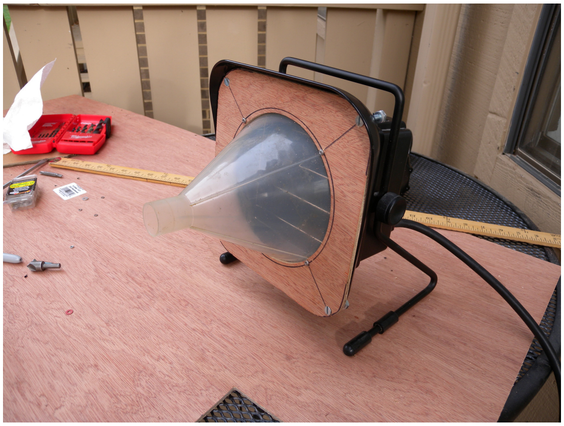
This system can be as simple as locally installing a fume extractor, like the tabletop model as mentioned in the previous section, or positioning the 3D printer near a window or other access point. In the case of having your printer near a window, it is important to ensure that the Makerspace has positive air-flow so that the fumes don't come back into the room.

A good way to test the proper functioning of your fume extractor is to touch a small amount of flux cored solder to the tip of a soldering iron near the location of your fume source while the extractor is turned on. You can then watch the path of the smoke as it rises and adjust the position of the extractor to intercept the vapors.

Ventilating Your Laser Cutter

The most overlooked part of purchasing a laser cutter is its ventilation system. This system is designed to provide a vacuum effect on the material bed as well as flushing the machine of material smoke and fumes. Each laser cutter has specific cubic-foot-per-minute (CFM) ventilation requirements that can result in a pretty sizable system. Generally, the system consists of a series of ductwork that extends from the back of the laser cutter and connects to a blower fan. This fan is then connected to duct work that is fed into an internal duct system or directly outside.

Project: Directed Smoke Absorber



If you find that your fume extractor cannot be properly positioned, it can be modified to localize the extraction point closer to your work. With a few simple tools and materials, this project will walk you through the steps to create a hose attachment for your WSA350. Although this project can be completed by hand, having access to a laser cutter makes is significantly easier!

This project requires safety glasses, which should be worn for the entirety of the project.

Materials

Materials List		
Item	**Quantity**	**Source**
Soldering smoke absorber	1	electronics distributor
6 in diameter plastic funnel	1	automotive parts store
1/8 in plywood sheet	1	home improvement store
6-32 × 2 in bolt	3	home improvement store
6-32 nut	3	home improvement store
#6 washer	3	home improvement store
2 in washing machine or sump pump utility hose	1	home improvement store
2.5 in hose clamp	1	home improvement store
1/2 in adhesive-backed insulation foam	1	home improvement store

Makerspace Tools and Equipment
1/4 in drill bit
1/8 in drill bit
C-clamp
Center-punch
Coping saw or equivalent
Power drill

Procedure

Step 1

Start by tracing the outline of the absorber onto the plywood sheet. Mark four holes approximately 1 inch in from the four corners. These will be used for securing the plywood to the absorber. Find the center of the of the outline and trace the shape of the funnel. Create a second circle concentric with the funnel outline that is approximately 1/4 inches smaller. This will allow for the funnel to be mounted to the plywood. Mark three holes around the perimeter of the outer funnel outline. These will be used for securing the funnel.

Step 2

Clamp the plywood sheet to the table by using the C-clamp and a scrap piece of wood. Then, using the center-punch, mark the center of the three holes by pressing the center-punch slightly into the material. Attach the 1/8 in drill bit to your drill and drill holes for the funnel mount. Make sure that you are drilling into an appropriate surface! Remove the bit, secure the 1/4 in drill bit to your drill, and drill out the mounting holes for the two brackets.

Step 3

Using the coping saw (Figure 1-14), carefully cut around the outlines you previously marked. Test fit the plywood plate onto your smoke absorber and trim away any excess material. Don't worry if you cut away too much material because you are going to seal the back of the plate with insulation foam.

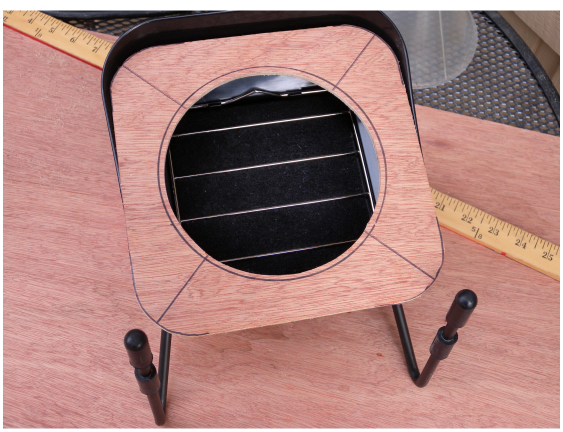


Figure 1-14. *Use a coping saw or jig saw to cut out the large hole in the center and outline of the plywood plate.*

Step 4

Mark a 1/4 in offset line around the back side of your plate. This line will act as a guideline for the insulation foam. Attach the insulation foam (Figure 1-15) to the back of the plate so that it follows the guideline. Secure the funnel onto the plywood by using the three 6-32 fasteners. Place the assembly onto the absorber and secure in place by using the 1/4 in fasteners.

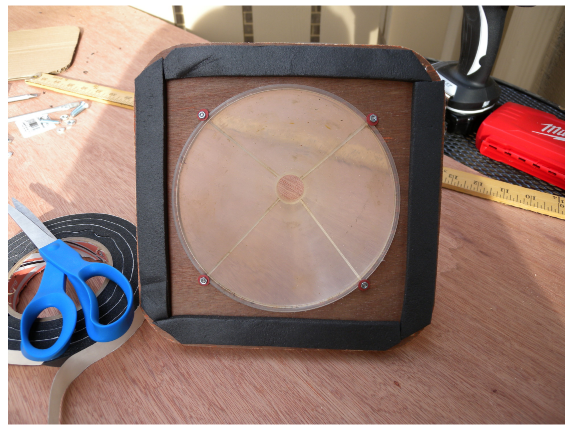


Figure 1-15. *Attach foam tape to the back of the plywood plate to prevent any air leaks.*

Step 5

Attach the hose to the hose adapter and fire up your smoke absorber. If everything is installed correctly, the vacuum produced should hold the plate in place and there should be a good vacuum now at the end of the hose. Position this hose as close to the fume source as necessary and secure in place with the hose clamp. Congratulations! You should now have a much more effective localized smoke absorber!